# DETERMINATION OF CLOUD PARAMETERS FROM SCIAMACHY DATA FOR THE CORRECTION OF TROPOSPHERIC TRACE GASES

**Michael Grzegorski[1], Christian Frankenberg[1], Ulrich Platt[1], Mark Wenig[2], Nicolas Fournier[3], Piet Stammes[3], and Thomas Wagner[1]**

[1]Institute of Environmental Physics, University of Heidelberg, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany
e-mail: michael.grzegorski@iup.uni-heidelberg.de
[2]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA
[3]KNMI, Climate Research and Seismology Department, De Bilt, The Netherlands

## ABSTRACT

For the accurate retrieval of tropospheric trace gases from SCIAMACHY the availability of cloud parameters is crucial. In this paper we present a new algorithm for the retrieval of cloud fraction from SCIAMACHY data, the Heidelberg Iterative Cloud Retrieval Utilities (HICRU). The reliability of the results are proven through intercomparision with cloud fractions from the FRESCO algorithm and images from Meteosat.

The new algorithm for SCIAMACHY is based on the already well validated HICRU algorithm developed for the retrieval of cloud fractions from GOME data. We use broad band spectrometers with high spatial resolution, the Polarization Monitoring Devices. The retrieval applies the widely used threshold method. Our sophisticated, iterative calculation of thresholds including image sequence analysis makes the algorithm also reliable in regions like deserts, which requires a very accurate set of thresholds.

Key words: HICRU; cloud fraction; SCIAMACHY, FRESCO.

## 1. INTRODUCTION

The SCanning Imaging Absorption spectroMeter for Atmospheric ChartograpHY (SCIAMACHY) on ENVISAT-1 allows measurement of different tropospheric trace gases (e.g. $NO_2$, $SO_2$, $CH_4$) using the Differential Optical Absorption Spectroscopy (DOAS) technique ([Platt (1994)], [Wagner (2002)]). Cloud detection algorithms are essential for calculating the vertical column density, because the Air Mass Factor (AMF) is strongly influenced by clouds. For precise retrieval of tropospheric trace gases, especially an identification of cloud free pixels is needed. The Heidelberg Iterative Cloud Retrieval Utilities (HICRU) provides a set of accurate cloud fractions calculated for each SCIAMACHY measurement. In the same way as other algorithms (e.g. FRESCO [Koelemeijer (2001)]), the results of the algorithm have to be interpreted as an effective cloud fraction, depended both on cloud coverage and cloud albedo.

The algorithm uses the intensities of the third Polarization Monitoring Device (PMD 3, 617-705 nm), which has a higher spatial resolution than the instruments used for DOAS evaluation of trace gases. The algorithm makes use of the threshold method: Lower thresholds represent the intensity of cloud free pixels and upper thresholds the intensity of cloudy pixels. Cloud fraction is obtained through linear intepolation between lower and upper threshold. Nevertheless the threshold concept cannot be applied directly to SCIAMACHY data, because the thresholds depends on different properties. The upper threshold depends on solar zenith angle (SZA) and the line of sight angle (LZA) during the measurement. But the most effort is necessary for the calculation of the lower threshold, because of its dependance on the earth albedo with significant spatial and seasonal variation. Further on the lower threshold is particulary important, because the detection of cloud free pixels requires an accurate lower threshold.

The presented algorithm is based on the already existing and well validated HICRU algorithm used with GOME data [Grzegorski (2003b)]. The results of the GOME algorithm are used as an important information for our retrieval of tropospheric trace gases (e.g. [Wagner (2004)], [Beirle (2004a)], [Beirle (2004b)], [Beirle (2004c)]). Note, that the presented results are preliminary. During the near future , the parameterization of the algorithm will be optimized. The validation studies are based on small datasets and are going to be extended.

## 2. CALCULATION OF THE LOWER THRESHOLD

Because of the dependency of the lower threshold on the seasonal variable earth albedo, image sequence analysis

*Proc. of the 2004 Envisat & ERS Symposium, Salzburg, Austria
6-10 September 2004 (ESA SP-572, April 2005)*

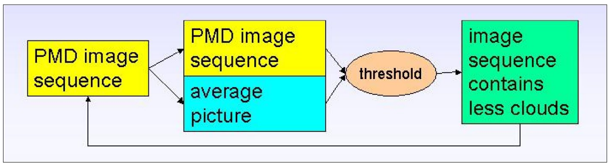


*Figure 1. Principle of the iterative fixpoint algorithm using image sequence analysis. HICRU uses this algorithm for calculating the lower thresholds, which represent cloud free pixels.*

is an appropriate approach for the retrieval of the lower threshold. The concept is shown in Fig.1. We start with an image sequence, which contains daily worldmaps of relative PMD intensities (the PMD intensities are divided through daily solar spectrum and the cosine of SZA). After cutting of pixels with intensities clearly higher than sahara, the image sequence can be used as input for the implemented iterative fixpoint algorithm (see Fig.1). Each picture from the image sequence is compared with the medium image obtained from the whole sequence: A pixel is identified as cloudy, if the difference between the single measurement and the value of the medium image is greater than the expected maximum seasonal variation of the lower threshold as estimated from case studies. This iteration threshold used for cutting off cloudy pixels during the iterations, depends on the period of time used for the input sequence. If we use the whole period of SCIAMACHY measurements, this iteration threshold has to be chosen higher than for short periods of time, because the change of earth albedo is greater for long periods. The result is an image sequence, which contains less data, because all measurements identified as cloudy are cuted off. Now, the algorithm is applied to this sequence and the described calculations are repeated until the image sequence does not change anymore. As result, we obtain the accumulation point of low intensities for each point on earth.

For the accurate retrieval of the lower threshold, two different strategies can be used. On the one hand, we could consider short periods of time, because the earth albedo changes with time and this variation can only be taken into account, if we calculate seasonal dependent thresholds. But long periods of time also have advantages, because a point on earth could always be cloudy, if we take less measurements into account. This is especially important in regions with persistent cloud coverage. The HICRU algorithms solves this problem through a three stage classification scheme.

- stage 1 applies the algorithm described above to all available SCIAMACHY data. The image sequence obtained as result is used as input for stage 2. The medium image of the retrieved image sequence after stage 1 is shown in Fig.2.

- stage 2 applies the algorithm to seasonal sets of PMD images. The iteration threshold used in the algorithm is smaller than in stage one, because of less variation in time is expected for stage 2. The result is used as input for stage 3.

- stage 3 calculates individual thresholds for each day. The algorithm uses periods of 37 days, 18 days before and after the day the thresholds are calculated for. As result, we obtain separate thresholds for each day (see Fig.3). But the pictures contain a lot of black points, which indicates that there is no more threshold available after step 3, because this point on earth was always cloudy. In this case, the lower threshold is interpolated using the earlier stages of the algorithm.

The HICRU algorithm can be applied to different PMD channels. Fig.4 shows the result for all PMD channels after stage 1 of the algorithm for Europe. We can see, that the threshold depends on earth albedo for all channels. Of course, the strength of this variation differs between the wavelength bands covered by the PMD. But there remain still some problems in our dataset, which leads to artifacts in the images of the lower thresholds. This problems need further investigations, but are probably due to problems with calibration of the PMDs. These problems in PMD channel 1,2 and 3 are smaller than in PMD channel 4,5 and 6. Overall, we decided to use channel 3 as best solution for most regions on earth with least problems and acceptable results.

## 3. CALCULATION OF THE UPPER THRESHOLD

For the calculation of the upper threshold, the usage of image sequence analysis is not reliable, because the threshold does not depend on earth albedo. We assume, that the upper thresholds can be determined through solar zenith angle and line of sight angle during the measurements. Nevertheless we also use an iterative algorithm for the upper threshold, which calculates the accumulation point of high intensities. All available SCIAMACHY PMD measurements are divided into datasets, which separate the data for different solar zenith and line of sight angles. The algorithm shown in (Fig.1) is then applied to these datasets instead of image sequences.

The result is shown in Fig.5. We found a dependency of the threshold not only on solar zenith angle, but also on the line of sight angle, which is not completely understood yet. These results for SCIAMACHY data are similar to the dependency of the thresholds calculated from GOME data on the subpixel of the measurement, which is in fact also an dependency on the line of sight angle. Our analysis of GOME data [Grzegorski (2003a)] has shown, that the calculated cloud fractions are improved by taking these relations into account.

The algorithm overestimates the upper threshold for high solar zenith angles, because ice and snow covered surfaces can refer to higher intensities than clouds with high albedo. Because of an ice correction routine implemented for GOME, the GOME algorithm is reliable for higher solar zenith angles than the SCIAMACHY algorithm so far. A similar ice correction will be implemented for SCIAMACHY soon.

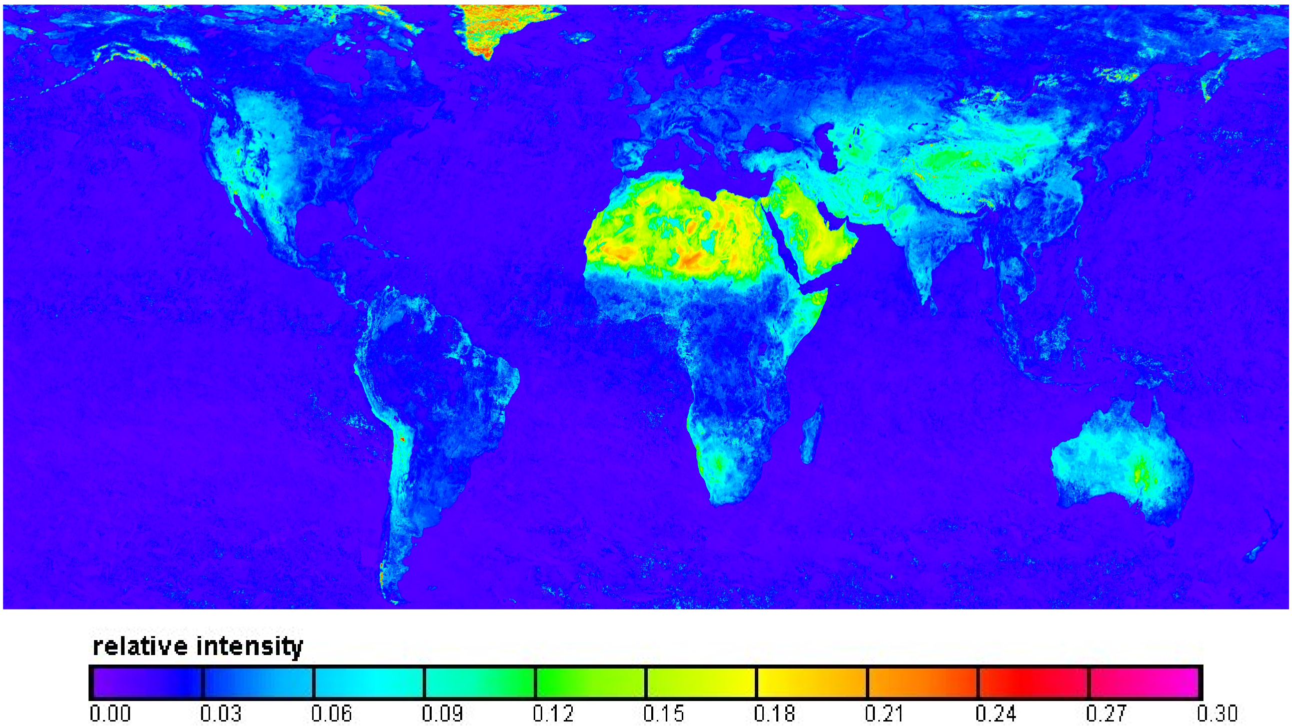


*Figure 2. Result of HICRUs iterative fixpoint algorithm for calculation of the lower threshold after stage 1. The image is retrieved from PMD 3 (617-705 nm) and the intensities are divided through daily solar spectrum and the cosine of the solar zenith angle. This medium image still contains some measurements with small, not vanishing cloud fractions, because the seasonal variation of earth albedo is not taken into account during stage 1.*

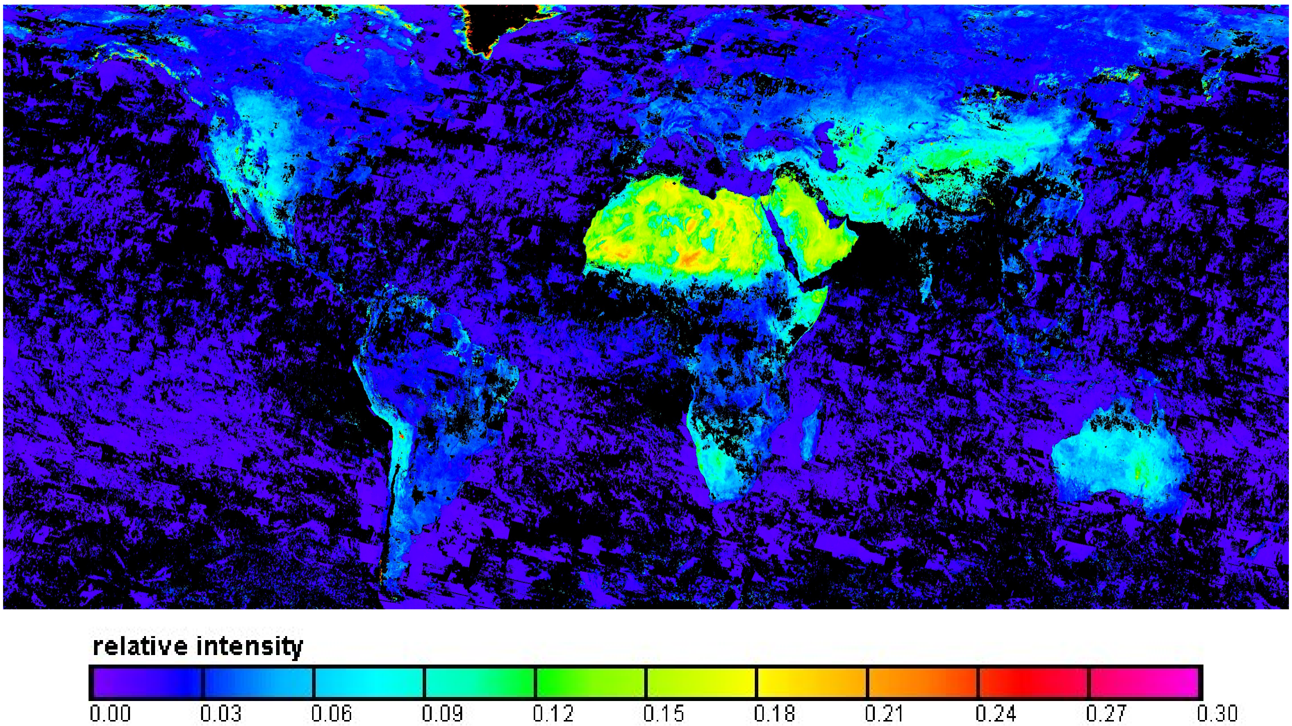


*Figure 3. Result of HICRUs iterative fixpoint algorithm for calculation of the lower threshold after stage 3. The image contains lots of black points, which indicate that during the considered short period of time (37 days) there was no measurement with vanishing cloud fraction.*

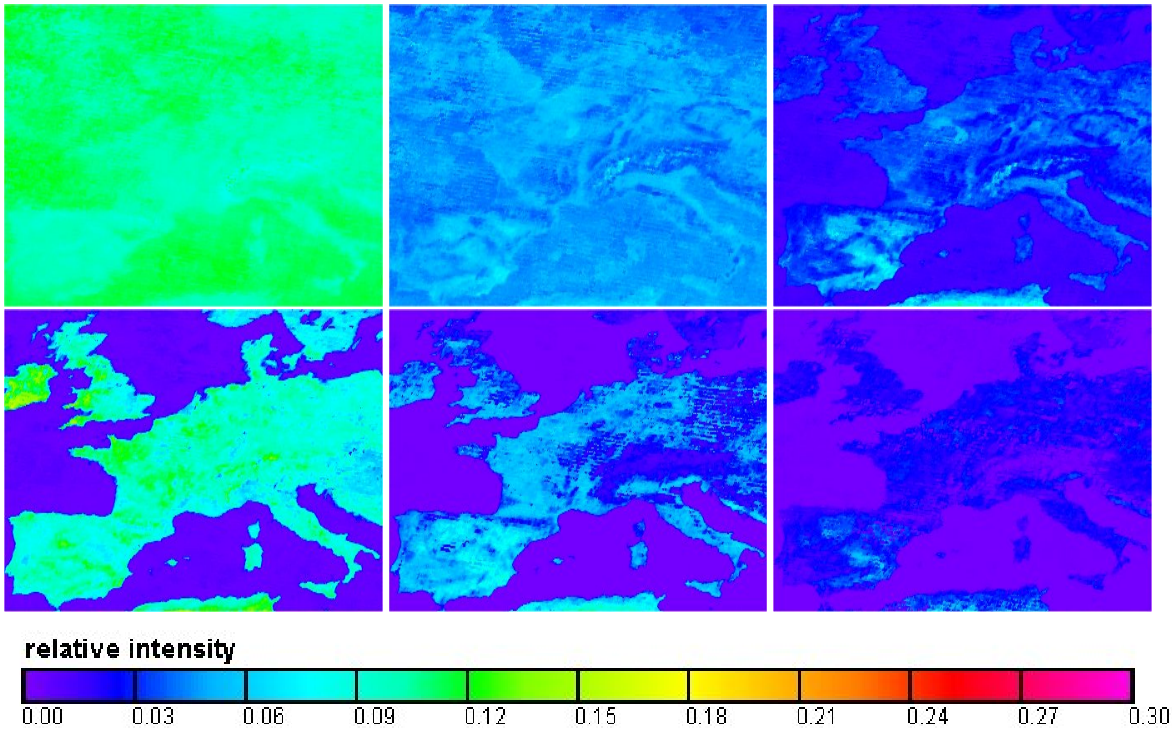


*Figure 4. Result of HICRUs iterative fixpoint algorithm for calculation of the lower threshold after stage 1 for different PMD channels over Europe: PMD 1 (310-377 nm) top left, PMD 2 (450-525 nm) top middle, PMD 3 (617-705 nm) top right, PMD 4 (805-900 nm) down left, PMD 5 (1508-1645 nm) down middle and PMD 6 (2290-2405 nm) down right. The intensities are divided through daily solar spectrum and the cosine of the solar zenith angle. Note, that there remain still some problems with PMD data, probably because of problems with calibration. This leads to some artifacts especially in PMD 4, 5 and 6.*

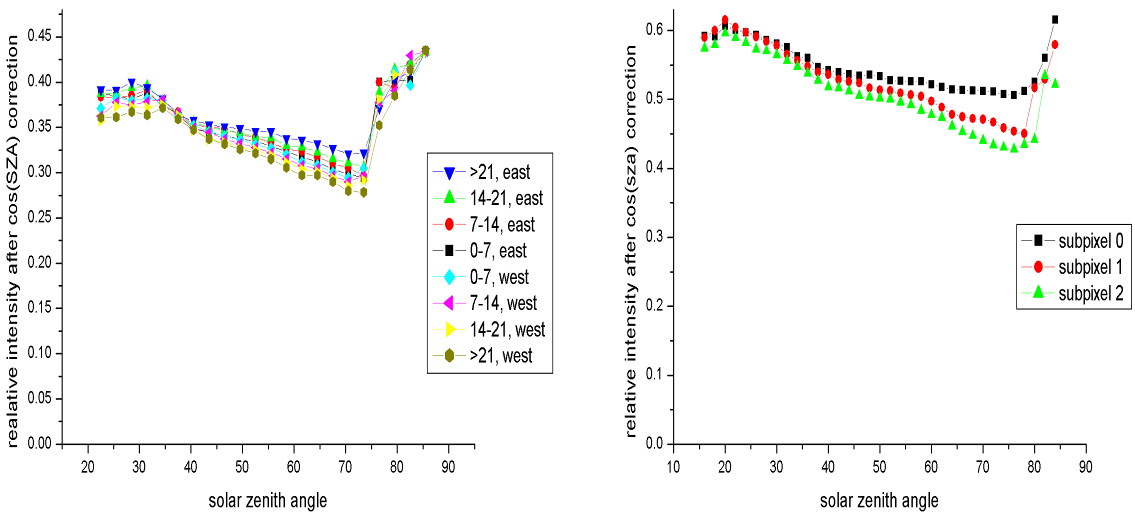


*Figure 5. Upper thresholds calculated with HICRU from SCIAMACHY data (left) and GOME data (right) [Grzegorski (2003b)]. High solar zenith angles have to be treated separately, due to problems with ice and snow covered surfaces.*

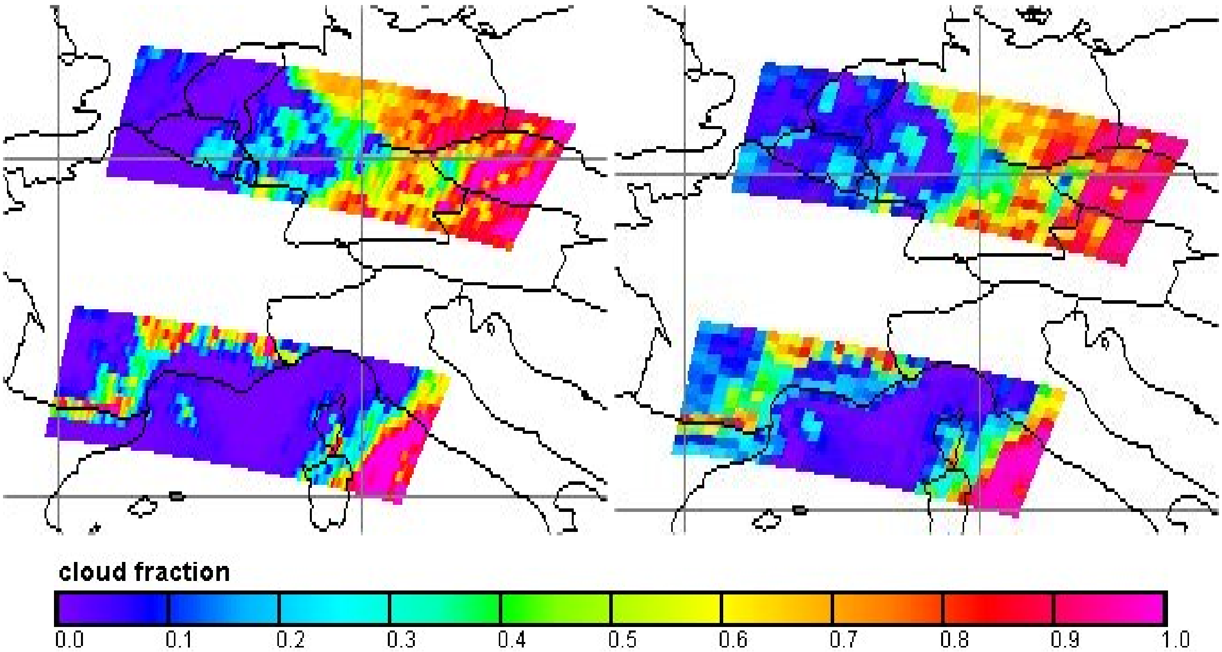


*Figure 6. Cloud fractions calculated with HICRU (left) and FRESCO (right) at January, 24th, 2003 over Europe. We found a good agreement.*

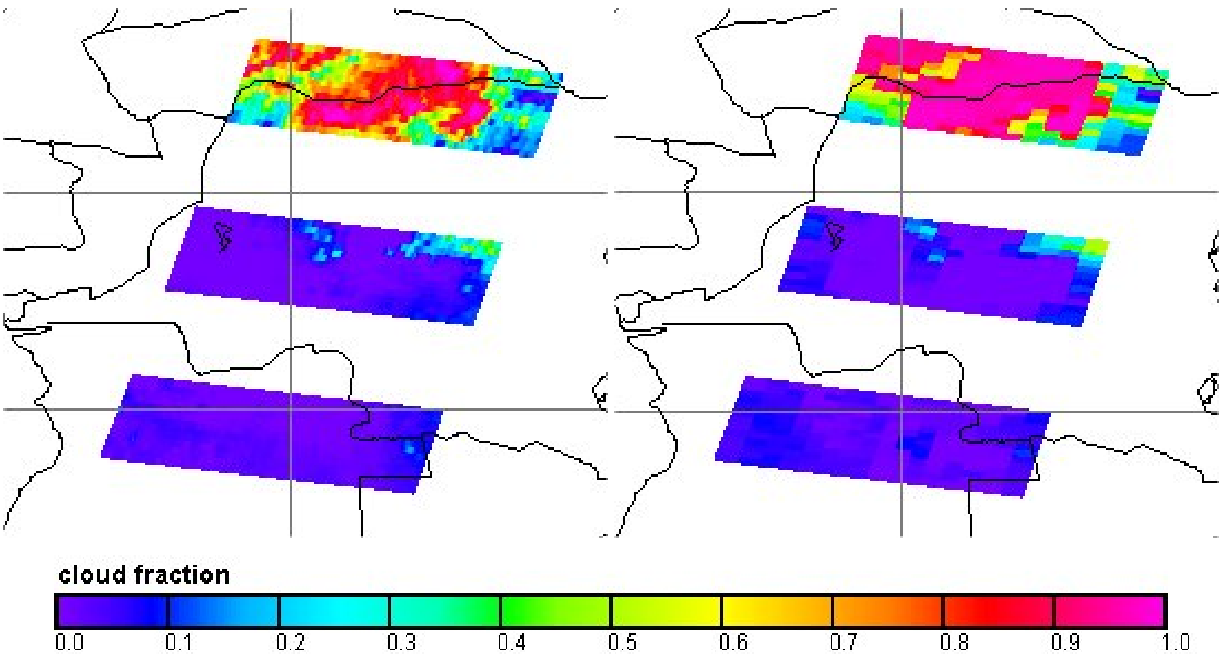


*Figure 7. Cloud fractions calculated with HICRU (left) and FRESCO (right) at August, 19th, 2003 over central Africa. We found a good agreement especially concerning the detected cloud free pixels. The cloud fractions from FRESCO in this example are higher than the cloud fractions from HICRU.*

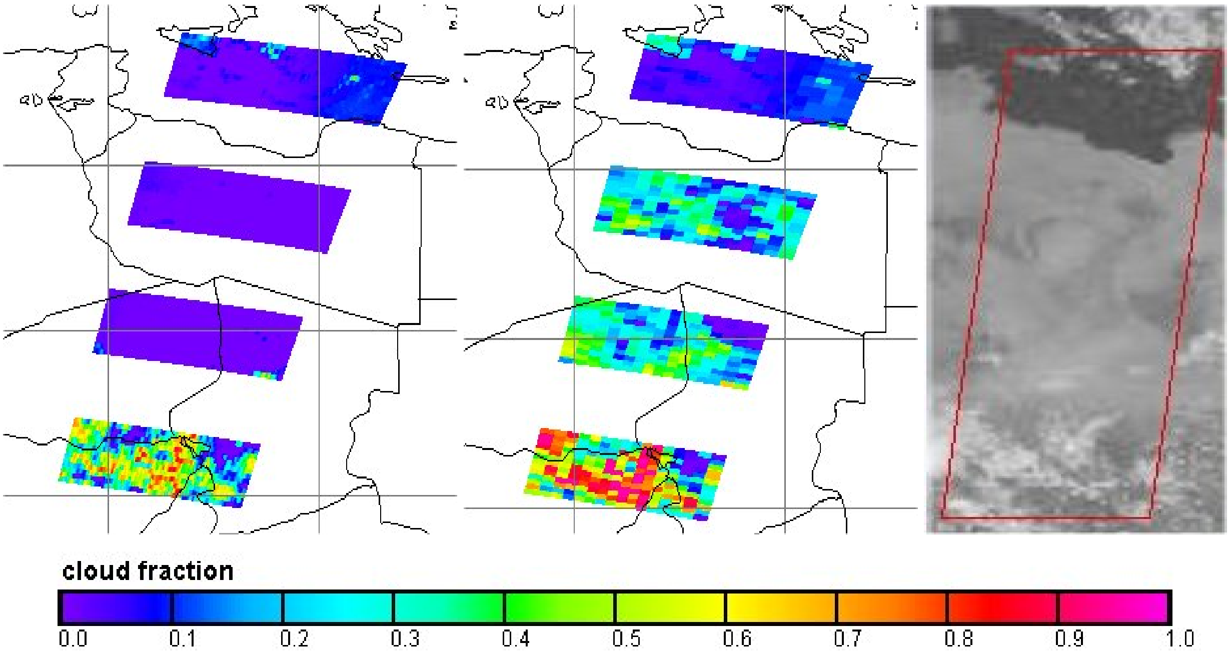


*Figure 8. Cloud fractions calculated with HICRU (left) and FRESCO (middle) at August, 27th, 2003 over sahara compared with an image from Meteosat (right, www.eumetsat.de). FRESCO overestimates cloud fraction over sahara, but the results from HICRU are reliable.*

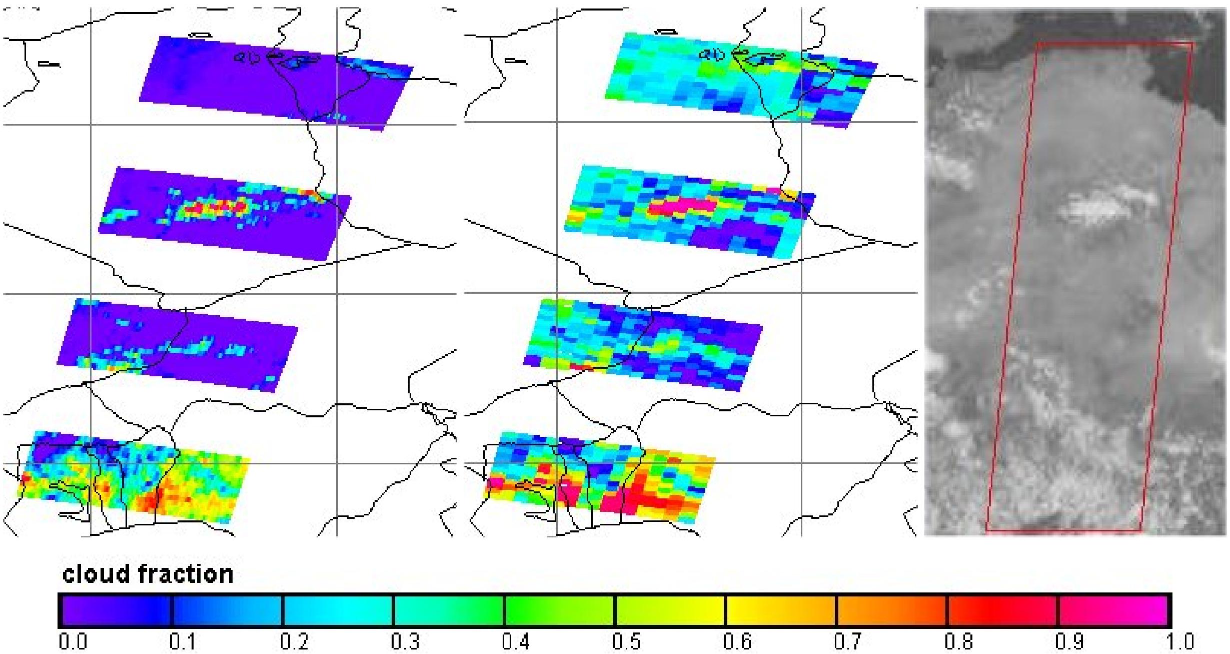


*Figure 9. Cloud fractions calculated with HICRU (left) and FRESCO (middle) at August, 13th, 2003 over Sahara compared with the image from Meteosat (right, www.eumetsat.de). HICRU detects the cloud over sahara reliable. Note, that the time of measurement differs about 3 hours between SCIAMACHY and Meteosat.*

## 4. INTERCOMPARISON WITH FRESCO DATA AND IMAGES FROM METEOSAT

We have validated our algorithm through intercomparison with images from Meteosat and data of the FRESCO algorithm. The FRESCO algorithm [Koelemeijer (2001)] calculates cloud fraction and cloud top pressure from SCIAMACHY and GOME data using the absorption in the $O_2$-A-Band and intensities around the $O_2$-A band. The spatial resolution of the HICRU cloud fraction is higher than FRESCO, because FRESCO uses the channels with spectral high resolution instead of the Polarization Monitoring Devices.

For intercomparison, we choose a limited set of case studies from four days of SCIAMACHY measurements in January and August 2003. In general, we found a good agreement between HICRU and FRESCO (e.g. Fig.6, Europe, 24.01.2003). However, we also found several examples, with higher cloud fractions calculated from FRESCO compared with HICRU e.g. in Fig.7 (19.8.2003, Central Africa). We cannot decide, which result is more accurate, but anyhow we found for this case study a very good agreement between both algorithms concerning the pixels detected as cloud free.

The HICRU algorithm also calculates accurate cloud fraction in desert regions. Through comparison with images from Meteosat we could show, that the HICRU algorithms calculates vanishing cloud fraction correctly in the case of cloud free sahara (Fig.8). In the case of cloudy sahara we also found an appropriate agreement between HICRU and the images from Meteosat (Fig.9). On the other hand, the FRESCO algorithm overestimates cloud fraction over sahara (Fig.8 and Fig.9), which is probably due to underestimated surface albedo over sahara in the database [Koelemeijer (2002)] used with FRESCO.

The cloud fractions from SCIAMACHY cloud algorithms are limited in the case of sun glint as well as snow and ice covered surfaces. In both cases it is impossible to retrieve an accurate cloud fraction with current algorithms.

## 5. CONCLUSIONS

We have developed a new cloud algorithm, the Heidelberg Iterative Cloud Retrieval Utilities (HICRU) for retrieving cloud fractions from SCIAMACHY data. The algorithm is based on the already well validated algorithm for GOME [Grzegorski (2003b)]. We use a sophisticated, iterative calculation of thresholds. The algorithm makes use of image sequence analysis for calculating the lower threshold. The upper threshold is calculated iteratively dependent on solar zenith angle and line of sight angle. We have compared the cloud fractions retrieved from our algorithm with results of the FRESCO algorithm and images from Meteosat. We found a general good agreement. The HICRU algorithm avoids problems of other existing cloud algorithms, especially we found no overestimated cloud fractions over sahara. There remain still some problems with the PMD data, especially in PMD channel 4, 5, and 6, which probably due to problems with calibration of the PMDs. Further investigations are necessary to fix these problems. Overall we use PMD 3 (617-705 nm) for cloud retrieval with HICRU as best solution with least problems for most regions on earth. In near future, we will add an improved parameterization of the algorithm and a better calculation of the upper threshold for high solar zenith angles through integration of information about ice and snow coverage.


## ACKNOWLEDGMENTS

We are grateful to EUMETSAT for providing us with Meteosat images (www.eumetsat.de) as well as to TEMIS project for providing us with FRESCO data (www.temis.nl).


## REFERENCES


Beirle S., U. Platt, R. von Glasow, M. Wenig, and T. Wagner, Estimate of nitrogen oxide emissions from shipping by satellite remote sensing, 2004a, Geophys. Res. Lett., 31, L18102, doi:10.1029/2004GL020312

Beirle S., U. Platt, and T. Wagner, Monitoring Nitrogen Oxides with Satellite Instruments: High resolution maps from GOME narrow swath mode and SCIAMACHY, 2004b, in ENVISAT Symposium, Salzburg

Beirle S., U. Platt, M. Wenig, and T. Wagner, Highly resolved global distribution of tropospheric NO2 using GOME narrow swath mode data, 2004c, Atmos. Chem. Phys. 4, 1913-1924

Fournier N. et al., SCIAMACHY cloud product validation, 2004, ACVE-2 workshop proceeding

Grzegorski M., Determination of cloud parameters for GOME with broad band spectrometers and from absorption bands of oxygen dimer (in German), 2003, diploma thesis, University of Heidelberg

Grzegorski M. et al., A new PMD cloud algorithm for GOME, 2003, EGU General Assembly, Nice, France.

Koelemeijer R.B.A., P. Stammes P., J.W. Hovenier and J.F. de Haan, A fast method for retrieval of cloud parameters using oxygen A-Band measurements from the Global Ozone Monitoring Experiment, 2001, J. Geophys. Res D, 106

Koelemeijer R.B.A. and P. Stammes, Validation of Global Ozone Monitoring Experiment cloud fractions relevant for accurate ozone column retrieval, 1999, J. Geophys. Res. D, 104

Koelemeijer R.B.A., J.F. de Haan and P. Stammes, A database of spectral surface reflectivity in the range 335-772 nm derived from 5.5 years of GOME observations, 2002

Platt, U., Differential optical absorption spectroscopy (DOAS), in Air Monitoring by Spectroscopic Techniques, 1994, M. W. Sigrist (Ed.), Chemical Analysis Series Vol. 127, John Wiley, New York.

von Bargen A. et al., Cloud retrieval algorithm for GOME (CRAG) Final Report, European Space Agency, 2000, 12678/98/NL/PR, ER-TN-DLR-CRAG-007

Wagner T., S. Beirle, M. Grzegorski, S. Sanghavi, U. Platt, Anomalies in global data sets of water vapour and cloud cover during the strong El-Nino event 1997/1998 derived from GOME, 2004, submitted to J. Geophys. Res.

Wagner T. et. al, Monitoring of trace gas emissions from space: tropospheric abundances of BrO, NO2, H2CO, SO2, H2O, O2, and O4 as measured by GOME, 2002, Air Pollution 2002, WIT Press, 10, 463-472.

Wenig M., 2001, Satellite measurements of long term global tropospheric trace gas distributions and source strength,PhD thesis, 2001, University of Heidelberg.